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THE DYNAMICS OF THE SHORE PLATFORM PROCESS, AND ITS RELATION TO CHANGES IN SEA-LEVEL

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Abstract

Sea-level is constantly fluctuating and consideration is given to the effect of this on the land/water interface, i.e. on coastal geomorphology. Soft rocks such as sand and clay are graded to present sea-level in the form of a gently inclined plane—the ultimate profile. Conversely, shore platforms occur above low water level in hard rocks. On the S. Gippsland coast an example is taken to show the different platform levels as a function of lithology. If this hypothesis be correct, then something of the history of recent sea-levels can be read from the coastal morphology of the hard rocks. The main point of the paper is to stress the dynamic nature of the shore platform process, as a result of the mobility of sea-level in the Quaternary.

Introduction

Although there is an important sense in which 'the present is the key to the past', there is another sense (also important) in which this is not true, because the Quaternary is quite different from all or most previous geological periods. One of these differences is the immense glacioeustatic changes of sea-level, one result of which is that the margins of the continents have passed through the strongly erosive wave zone, not once, but a number of times. The transgression of the sea from far out on the continental shelf to inland of the present shore in a number of erosive sweeps has created a 'plain of marine denudation' of exceptional width.

For the present purpose it should be noted that the migrations of the land/water interface at relatively high speed to and fro across the continental margins means that shorelines are mobile and their structures ephemeral from the point of view of geological history. Most shoreline features are novelties. The shore platform is a process rather than a condition; the function is not static but dynamic. Instead of viewing the shore from the viewpoint of our own short lives (or more accurately, our own short memories), we should undoubtedly think in terms of a dynamic geomorphic process. What we see is but a phase in a series of rapid changes; the milieu is an evolutionary one.

The beach we visit may appear the same this summer as last summer, but if we measure it, we discover this is not so. Not only is much of the morphology new, but also much of the material. Sand contained in the beach last summer has been blown into dunes or washed away by longshore currents. There is a sand budget with the period of changeover differing according to the dynamics of the site. Similarly, the rock platform that in a general way seems the same as a year ago is found to be different if measurements are taken. The sum of such differences over a century is appreciable.

Thus it is proposed that the height of a shore platform is a balance between a number of active factors, viz. the resultant of:

1. The oscillations of sea-level.
2. The nature of the rocks forming the shore.
3. The effectiveness of marine erosion at that site (including waves, chemical solution, spray, and marine life).

4. The climate of the area, and so the nature of the subaerial erosion.
5. Other factors (including the water table).

The process is complex, so any theory involving only one factor is inadequate. The above factors will be examined in the course of the paper.

Sea-level is Mobile

Radiocarbon dating has shown that the glaciations of the northern and southern hemispheres (within its time-range and so presumably throughout the Ice Age) were contemporary, and that sea-level changes were in phase with changes in the world's ice budget. Growth of ice caps meant lowering of sea-level, and melting of the ice caps meant rise in sea-level. The major component in present sea-level change is therefore glaciocustasy. But the ice regime is constantly changing, and so sea-level also is constantly changing. In addition there are the slower changes brought about by sedimentation in the sea, by flexing of ocean floors, and by continental tectonics, besides the expansion and contraction of the water itself with change of temperature. The general acceptance of the mobility of sea-level is very recent, and so all its implications have not yet become clear. In this paper it is suggested that it has implications for shore platform formation.

Following the low sea-level of the Last Glacial, the sea rose rapidly. This Flandrian Transgression was not a straight rise of sea-level. Oscillation has been superimposed upon oscillation. Short-period changes have been superimposed on the effects of major climatic changes such as the Alleröd. Some claim that since the Flandrian Transgression brought sea-level to its present height, sea-level has stood still. If this is meant literally, then it is incorrect, because sea-level is too mobile for that. Fairbridge (1961) has hypothesized a series of sea-level changes through the past 5,000 years; some have claimed that he postulates too many oscillations, but from the point of view of the principle of a mobile sea-level, there are not enough. Tide-gauges, shoreline morphology, and other data show that the contemporary sea-level is mobile, and this has undoubtedly been its condition during and since the Flandrian Transgression. A mobile sea-level is a Quaternary characteristic.

Now this has important implications for shore platforms. If sea-level be as mobile as this, then only the platforms in soft rocks will be fully adjusted to contemporary sea-level, while the cutting of platforms in hard rocks will lag behind. This could account for much of the observed differences in the levels of rock platforms, because it is the hard-rock ones that are more emerged and the soft-rock ones that are less emerged. Other factors being equal, the elevation of shore platforms is a function of lithology.

Lithology Affects Development

On the same coast, under the same conditions of climate and marine attack, shore platforms nevertheless exist at different heights above LWL. This is believed to be a function of differential lithology. For example, on the coast of eastern Victoria, between Inverloch and Cape Paterson (Pl. 31-34), there are platforms consisting of mudstone, others of sandstone, and yet others that have areas of sandstone turned to ironstone by secondary deposition of red iron oxide. A survey showed that the height of the platform was a function of the resistance of the rock to erosion. Thus at the west end of Venus Bay near Inverloch where a sandy coastal barrier gives way to the cliffs of Cretaceous freshwater sediments, the lithology of the shore platform is mudstone and it is graded to sea-level in the same way as the contiguous sandy beach. However, many large concretions caused by deposition of secondary carbonate occur there in the shore platform and in the cliff. These stand above the shore platform, holding up erosion, and by differential erosion they also jut out of the cliff. A couple of concretions about 2 ft in diameter were broken off along lines of weakness—cracks infilled with calcite. The small point on the coastline at this place is a result of the slowing down of erosion by the calcitic concretions.

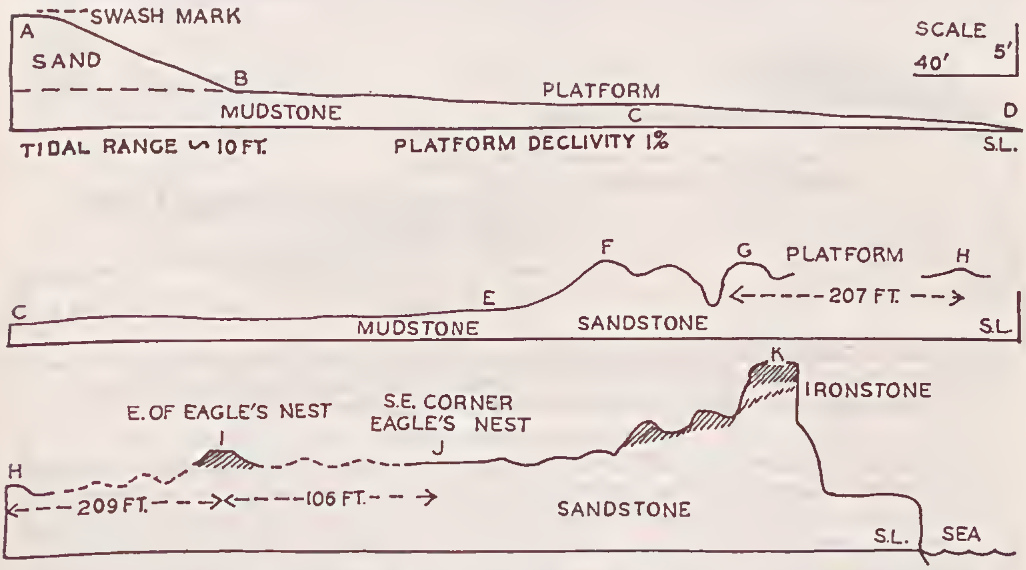

Fig. 1—Three successively higher shore platform levels at Eagle's Nest, Cape Paterson coast, E. Victoria, in Lower Cretaceous mudstone, sandstone, and ironstone respectively.
Section A-D surveyed normal to the shore from the beach swash mark to low water mark. The lithology is stratified mudstone striking in the direction of the section.
Section C-H surveyed from point C in the middle of Section A-D, and traversing approximately parallel to the shore. The change of level between E and F is coincident with the change in lithology from mudstone to sandstone.
Section H-K is a continuation of the Section C-H to Eagle's Nest islet. The changes of level in the vicinity of I and K are coincident with the occurrence of ironstone. In these areas the sandstone is impregnated with red iron oxide. High ramparts as at K are not always at the outer edge of the platform, but may occur wherever there is sufficient ferruginization to make the rock more resistant to erosion.

Eagle's Nest is a small island or large rock stack (Pl. 32, fig. 2) off a prominent point on this coast, the general character of which can be seen in Pl. 31, fig. 1. On the east side of Eagle's Nest there is a platform of mudstone about 300 ft wide with a pocket beach (sand) at the landward end. A survey of this platform normal to the shore is shown in Fig. 1. Where surveyed, there was a fall of 3·16 ft in the 294 ft of the platform from the seaward edge of the sand to low sea-level (B-D), a declivity of about 1 per cent. The platform is smooth except for fine ridges resulting from slight differences in hardness and/or toughness. The strike is normal to the shore, but the same kind of platform occurs where the strike is parallel to the shore (Pl. 31, fig. 2). From the middle of the platform (C), a traverse line was surveyed approximately parallel to the cliffs and about three chains from them. Fig. 1, C-G, shows the abrupt change with change of lithology from mudstone to sandstone. Whereas the mudstone platform is more or less even, the sandstone platform is very dissected—clear evidence that it is in process of being reduced to a lower level. Near Eagle's Nest, and particularly on the seaward side of it, the sandstone is slightly hardened by impregnation with yellow iron oxide, but the really resistant rocks are those impregnated with red iron oxide (Pl. 32, fig. 2; Pl. 34, fig. 1). It appears that the yellow iron oxide is due simply to the oxidation of the country rock while the red iron oxide is secondarily introduced.

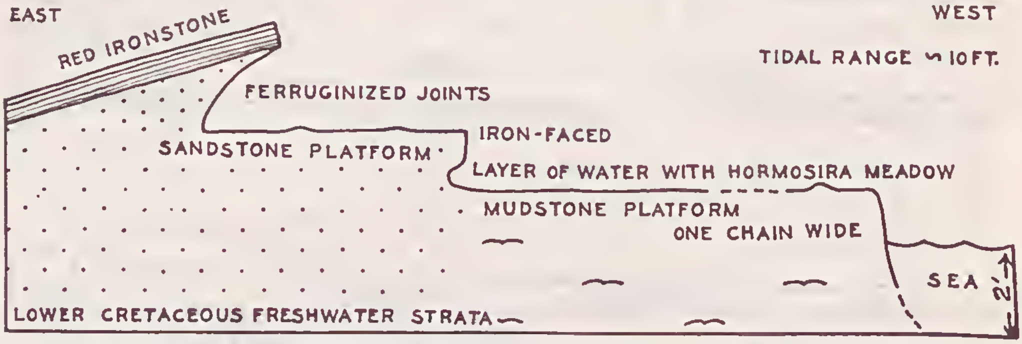

Fig. 2—Section of shore platforms on the west side of Eagle's Nest, Cape Paterson coast, Gippsland, Victoria, showing the effect of lithology on platform height.

Fig. 1, C-K, shows the effects of competence on platform cutting on the E. side of Eagle's Nest. The low platform in mudstone is succeeded by a higher one in sandstone, and then higher outcrops again controlled by the presence and disposition of rocks with red iron oxide. The same effects of lithology can be seen in microcosm in places where the mudstone is conglomeratic (cf. Pl. 33, fig. 2). The pieces of included sandstone stand up above the mudstone, while fragments of red ironstone stand highest of all. Similar profiles (large and small) occur in vertical section in the cliffs. In Pl. 33, fig. 1, a silicified trunk shows clearly the effects of differential erosion; fig. 2 shows difference in platform level caused by difference in lithology on the W. side of Eagle's Nest.

Similar features to those described can be seen further west near Cape Paterson and at Kileunda. They may likewise be seen in the Mesozoic rocks in the vicinity of Sydney, e.g. at Whale Beach, where there is a sudden drop of level from the sandstone platform to the mudstone one.

Comparative Lithology of Shore Platforms

When it was noted how important a part lithology played in the genesis of shore platforms, a survey was made of platforms cut in varying lithologies, and the following principles were noted:

1. The softer the lithology, the lower the platform. Conversely, the harder and tougher the rock, the higher it stands.
2. The softest rocks are graded down to present sea-level with a profile similar to that of sandy beach—the 'softest' of the substrates.
3. The low platforms are very even while the high platforms are very irregular. The higher the platform, the more irregular it is.
4. From the foregoing, it is inferred that platforms are in process of being brought into balance with present sea-level. This is readily achieved with soft lithologies but is naturally slower with more resistant rocks.

5. Concomitance of summit level indicates the former presence of platforms at a higher level.

The softest consolidated substrate studied was clay. At Point Henry, at the east end of Corio Bay, Victoria, there is a cliff 50 ft high of clay fronted by a shore platform of the same material. On shallow depressions in the platform there is some soft clay which has been washed from the cliffs. The profile has a declivity of about 1·2 per cent. Scanning by eye gave no evidence of departure from this order of slope. Minor erosion of the platforms continues, but essentially it is in equilibrium with present sea-level. A similar clay platform can be seen at Fossil Beach near Mornington in Port Phillip. The clay at Point Henry is dated as Quaternary by Spencer-Jones (1963), while the clay at Fossil Beach is Miocene. The former is non-marine and includes pedocalic soil profiles in three main horizons, while the latter is marine.

Aeolianite (dune calcarenite) presents an intermediate degree of platform reduction about half way between clay and the hard Mesozoic sandstone. The platforms are usually of low declivity and their height above LWM appears to vary according to the resistance of the rock, and the nature of marine attack, but all are below mean sea-level (Gill 1954). Solution and abrasion are both factors in their reduction.

It should be noted that no platform is perfectly even, nor any perfectly horizontal. There are usually two elements in their structure: (1) a seaward slope and (2) a varying amount of surface differentiation. As already noted, the higher platforms are the more differentiated. Shore platform and cliff both show differential erosion, but the cliff is usually more uneven than the platform. The reason is that marine planation smooths many of the protuberances that would otherwise occur in platforms if subaerial erosion alone occurred (Pl. 32, fig. 1).

That gulches may be cut in shore platforms down to low water mark (or even below) demonstrates how low the sea can cut. Pl. 34, fig. 2, shows such a gulch eroded where a dyke cuts across the platform on the Cape Paterson coast in Victoria. As the sides of the gulch are free of marine growth while other surfaces nearby are thickly coated with it, the gulch sides must be in process of active erosion. Appreciable quantities of marine growth or sediment occur only on the low shore platforms; their absence from higher platforms is due to their active erosion.

The Ultimate Profile

Given sufficient time, what is the profile to which the sea will ultimately erode a rock platform? It is suggested that the profile established on a beach is the ultimate profile (this term is not used in a technical sense). There the rock (geologists use this term for unconsolidated materials as well as lithified ones) is the most easily eroded of all, and therefore keeps in equilibrium with the forces of the sea. The amount of cut and fill will vary according to the dynamics of the beach concerned, but the gentle declivity seaward is characteristic of beaches. Tidal range affects the angle of declivity, but it is always low. There is a balance between the dynamics of the water and the resistance of the sand (assuming an adequate supply of the latter).

The antithesis often presented between beaches and rock platforms can be misleading. One may grade into the other. It may be noted that where the rocks eroded are very soft, the profile is of the same kind as is found on beaches. Thus at Point Henry in Corio Bay, Victoria, there is a clay cliff and clay shore platform which has a gentle declivity towards the water such as occurs on the contiguous sandy beach.

Analogous Lacustrine Shore Platforms

There is an analogy between marine and lacustrine shore profiles. For example, at Lake Colongulac in Western Victoria (Gill 1953), mid-Holocene lacustrine shell-beds (Gill 1964), and the overlying windblown clayey silt (parna) are being rapidly eroded by lake waves to form an ultimate profile similar to a marine one. The parna is more easily eroded than the shell-bed, and so a small platform of shell-bed may occur, but this also is gradually reduced to the ultimate profile.

However, where the outcropping rock is basalt, which is too hard to be eroded rapidly, the shore platform emerges. Some of the basalt platforms are comparatively old, e.g. on the SE. side of the lake, shell-beds of the order of 14,000 years old are partly stripped from a basalt platform. Thus although lake level fluctuates (as does the level of the sea), the soft rocks are rapidly reduced to a profile of low declivity in balance with the dynamics of the lake waters (an ultimate profile), while the basalt takes a very long time to be eroded down to the same profile. The emerged basalt platform has nothing to do with storm waves (an explanation given for high rock platforms along the sea shore), but is simply a function of lithology in relation to the dynamics of the eroding waters.

Rock Structures and Shore Platforms

It has often been pointed out that some rock platforms owe their development to structures in the rocks forming the coast (Jutson 1950; Hills 1940, fig. 284; Edwards 1941). A soft rock can be stripped from a hard one, and so leave a platform. Similarly a weak stratum can be eroded from a compact stratum, or decomposed rock removed from fresh rock; or a zone of rock may be quarried out so as to cause collapse of the overlying rocks and thus develop a platform. Similarly, a fossil soil may be excavated by wave action, causing collapse of the cliff above, and when the debris is cleared by the sea, a platform remains. Likewise, soft calcarenite may be swept from a zone lithified by deposition of secondary carbonates.

Development of a platform may also be affected by the cleavage in a rock formation, by the presence of joint planes, and by the incidence of such planes and of faults—large and small. The tendency to decrepitate on exposure to subaerial agencies (especially wetting and drying) is a feature of many siltstones, so that what appear to be strong strata become weak under certain conditions. Likewise rocks vary in their tendency to break up when frozen and thawed, or subjected to salt crystallization. On the Port Campbell coast in Western Victoria, cliffs of Miocene marine limestone occur up to 200 ft high, and face the Southern Ocean, there being no land between this coast and Antarctica. It is thus a high energy coast. The earthy limestone has a vertical cleavage, so that it is common for a fissure to develop which separates off a segment 20 to 30 ft long, as high as the cliff, and five to six ft wide. Rain water pours down such cracks, and further weakens the structure. Storm waves quarry out these gigantic blocks, so that they collapse into the sea, where they are broken up by the turbulent waters. In protected bays they may drop down, still leaning against the cliff. The cleavage does not appear to go further than the level of the narrow shore platform (where present), below which is constantly damp and relatively unoxidized rock.

Highly soluble rocks are naturally affected by the presence of water, and then solubility of the rock is a factor in platform formation. Hodgkin (1964) calculated a mean reduction of 1 mm per year for an aeolianite platform in Western Australia.

Thus the lithology of the coastal rocks is a definite factor in shore platform formation, as many authors have indicated.

Effectiveness of Marine Erosion

If the sea were immobile the only erosion would be by solution. If there were only waves of oscillation they would impinge on the cliff or the vertical wall forming the outer edge of many shore platforms, and be reflected out to sea again, having little (if any) effect. It is the waves of translation (in the sense of breaking waves) that erode, especially when armed with sand and rocks. Thus the outer wall of the platform is covered with organisms, while the surface of the platform is more often than not scrubbed clean except where hollows and scour holes provide some protection, but even there growth is limited. On a high energy coast, large boulders are quarried from the cliffs and litter the sea floor in front of the platform—to the distress of fishermen. They also are covered with marine growth as are the bases of truncated islands and rock stacks.

While solution, water layering (Hills 1949), and such processes operate chiefly at rock platform level and thereabouts, storm waves, salt spray and such agencies operate over great heights. Storm waves on the Port Campbell coast mentioned above, may splash 50 ft above the 200 foot cliffs, stripping the edges in many places (Baker 1958; Ongley 1941). The salt spray spreads further still, drifting inland, and some salt travels hundreds of miles to descend as cyclic salt far from the coast (Anderson 1945). Storm waves exercise their maximum attack at different levels according to tidal conditions, wind force, wave size and incidence, and other factors. Thus to attribute a horizontal platform in a homogeneous rock to storm waves appears unreasonable to the writer.

This argument applies even more to salt spray which attacks the whole coastal facade and the terrain for some distance inland. Even in the climatic conditions that best suit this kind of erosion (Tricart 1959) one cannot imagine a process whereby a level platform is attained, if the rock be homogeneous. On the coast at Goose Lagoon in western Victoria, waves erode the coastal basalt smooth except for well sheltered sites above HWL which may be honeycombed, presumably by salt spray etching. At Whale Beach, N. of Sydney, honeycombing on a much larger pattern is seen high up on the cliff faces, and it appears to be a function of salt spray erosion (cf. Bartrum 1936).

Solution operates on every coast, but to different degrees. All rocks are in some degree soluble. A calcarenite coast may lose much mass by solution, but it may also gain. In hot, dry weather, carbonates dissolved in spray may be soaked up in the lime sand, the water evaporated, and secondary carbonate deposited. In this way the sand is lithified, and resistance to erosion increased. This process has been observed in Victoria on the Sorrento Peninsula and in the Warrnambool district.

Marine and Subaerial Erosion

Shore platforms occur in the zone of overlap of marine erosion and subaerial erosion. Rain falling on the land seeps through porous rocks or along structural cavities such as joint planes and caves. If the rainfall is high there will be a hydrostatic pressure of water pressing towards the sea. With variations in lithology, season, and climatic cycle, the water-table may be variable. Likewise, as already described, sea-level is mobile. With the variation in the water-table there is variation in the penetration of air, and so also in the processes of oxidation, carbonation, and so on. All three systems of ground water, sea water, and air are dynamic, and their 'eutectic point', so to speak, is at or near the level of the shore platform. Thus the cutting of a shore platform may be related to the base of oxidation in the country rock, or to the level of constant water saturation, as well as to the erosive sea/air interface. But for all three the nature of the country rock is important—its porosity, its degree of weathering, its diagenesis, and its competence to resist marine attack.

It seems to the writer that there are four important processes at work (but others as well) reducing the level of the shore platform, viz.:

(a) Chemical weathering (including oxidation, carbonation and the effects of salt). This is particularly significant in humid tropical areas where warm copious waters rapidly rot the country rock.

(b) Abrasion by the waves, especially when they are armed with sand, rocks, and other abrasive tools.

(c) Solution, a chemical process at work on all rocks, but particularly effective on carbonates because of their high solubility.

(d) Wetting and drying, a physical effect noted especially in fine grained sedimentary rocks such as siltstones. Rocks otherwise hard and tough will decrepitate under such conditions and so readily disintegrate. A given rock will develop a characteristic pattern of decrepitation cracks under wetting and drying.

Genesis of Shore Platforms

Bird (1964) has provided a very helpful treatment of coastal landforms, but he is obviously puzzled about shore platforms. He describes two kinds of shore platforms (for which there may be two kinds of process), viz.:

(a) Intertidal platforms which are slightly inclined seaward.

(b) High tide platforms which are horizontal.

Bird's intertidal platform is the ultimate platform of this paper. If there were only 'intertidal platforms' graded to LWL and 'high-tide platforms' graded to HWL, an hypothesis of two processes could be considered, but the fact is that platforms at all levels in-between do occur. The hypothesis advanced here is that all higher platforms are stages in the process of reduction to the ultimate platform.

Bird (p. 52) suggests that storm waves 'are responsible for the recession and dissection of the outer edge of the high-tide platform, particularly along joints and bedding-planes, rather than the planation of the platform itself'. However, it should be noted that such outer edges are usually strongly protected by biologic layers (calcareous algae, seaweeds, barnacles, molluscs, tunicates, etc.), while the platform is comparatively bare, such life as occurs being in protected places. Close examination of the platform shows it is suffering abrasion.

If calm seas erode at one level and storm seas at another, then there should be duplication not only of platforms but also of other features such as the wave-cut nip. I regard the wave-cut nip as the homologue on the rocky coast of the swash area of the beach. In the swash area the waves breaking on the sandy beach dissipate their excess energy. At the wave-cut nip the waves normally expend their excess energy by rolling back on themselves at the nip.

An hypothesis of high and low tide platforms is unable to explain the structures at Eagle's Nest described above where in the space of a few hundred yards there is an 'intertidal platform' and a 'high-tide platform', with other levels in-between, and the differences are coincident with changes in the hardness of the rock. The hypothesis presented in this paper is looked upon as but another approximation, for we are still very ignorant about these processes. However, if it be proved that higher platforms are just those in process of reduction to the ultimate platform, then at some time in the not too distant past the ultimate platform must have been much higher, and this infers a higher sea-level or emergence of continental magnitude.

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